CLAIMS

What is claimed is:

1. An electromagnetic actuator, comprising:

first and second magnetic members;

a first electromagnetic coil;

the first magnetic member being moveable relative to the second magnetic member between first and second positions, and being electromagnetically attracted to the first position by electrical excitation of the first electromagnetic coil; a first preloaded spring configured to apply a first spring force to the first magnetic member biasing the first magnetic member towards the second position only when the first magnetic member is in or between the first position and some fraction of its travel from the first position to the second position.

2. The actuator of claim 1, further comprised of a second preloaded spring configured to apply a second spring force to the first magnetic member biasing the first magnetic member towards the second position when the first magnetic member is in or anywhere between the first and second positions.

3. The actuator of claim 2, wherein the actuator requires a holding electrical current in the first electromagnetic coil to maintain the first magnetic member in the first position.

4. The actuator of claim 2, wherein the first magnetic member will magnetically latch in the first position by residual magnetism, without use of a holding electrical current.

5. The actuator of claim 2, wherein the actuator has first and second ends, and wherein the first electromagnetic coil and the first and second preloaded springs are adjacent the first end of the actuator.

6. The actuator of claim 2, wherein the actuator has first and second ends, and wherein the first electromagnetic coil is adjacent the first end of the actuator and the first and second preloaded springs are adjacent the second end of the actuator.

7. The actuator of claim 2, wherein the first and second preloaded springs are adjacent opposite ends of the actuator.

8. The actuator of claim 1, further comprised of a second electromagnetic coil, the first magnetic member being electromagnetically attracted to the second position by electrical excitation of the second electromagnetic coil.

9. The actuator of claim 8, further comprised of a second preloaded spring configured to apply a second spring force to the first magnetic member biasing the first magnetic member towards the second position when the first magnetic member is in or anywhere between the first and second positions.

10. The actuator of claim 9, wherein the fraction is less than approximately one half.

11. The actuator of claim 9, wherein the fraction is in the range of approximately one fifth to approximately one fourth.

12. The actuator of claim 1, wherein the actuator has a zero nonmagnetic gap when the first magnetic member is in the first position.

13. The actuator or claim 12, wherein the first magnetic member is a spool of a spool-type fluid control valve.

14. A spool-type fluid control valve, comprising:

a magnetic spool and a magnetic spool valve housing, the spool being moveable relative to the housing between first and second positions;

a first electromagnetic coil disposed in the housing and operable to electromagnetically attract the spool to the first position upon electrical excitation of the first electromagnetic coil;

a first preloaded spring configured to apply a first spring force to the spool biasing the spool towards the second position only when the spool is at any of i)the first position, ii) anywhere between the first position and some fraction, less than one, of its travel from the first position to the second position, and iii) the fraction of its travel from the first position to the second position.

15. The spool-type fluid control valve of claim 14, further comprised of a second preloaded spring configured to apply a second spring force to the spool biasing the spool towards the second position when the spool is at any of i) the first position, ii) the second position, and iii) anywhere between the first and second positions.

16. The spool-type fluid control valve of claim 15, wherein the spool valve requires a holding electrical current

in the first electromagnetic coil to maintain the spool in the first position in opposition to the first and second spring forces of the first and second preloaded springs.

17. The spool-type fluid control valve of claim 15, wherein the spool will magnetically latch in the first position by residual magnetism, without continuous use of a holding electrical current in the first electromagnetic coil, in opposition to the first and second spring forces of the first and second preloaded springs.

18. The spool-type fluid control valve of claim 15, wherein the spool has first and second ends, and wherein the first electromagnetic coil and the first and second preloaded springs are located adjacent the first end of the spool.

19. The spool-type fluid control valve of claim 15, wherein the spool has first and second ends, and wherein the first electromagnetic coil is located adjacent the first end of the spool and the first and second preloaded springs are located adjacent the second end of the spool.

20. The spool-type fluid control valve of claim 15, wherein the spool has first and second ends, and wherein the first and second preloaded springs are located adjacent opposite ends of the spool.

21. The spool-type fluid control valve of claim 14, further comprised of a second electromagnetic coil, the spool being electromagnetically attracted to the second position by electrical excitation of the second electromagnetic coil.

22. The spool-type fluid control valve of claim 21, further comprised of a second preloaded spring configured to apply a second spring force to the spool biasing the spool towards the second position when the spool is at any of i) the first position, ii) the second position, and iii) anywhere between the first and second positions.

23. The spool-type fluid control valve of claim 22, wherein the fraction is less than approximately one half.

24. The spool-type fluid control valve of claim 22, wherein the fraction is in the range of approximately one fifth to approximately one fourth.

25. The spool-type fluid control valve of claim 14, wherein the spool has a zero nonmagnetic gap relative to the housing when the spool is in the first position.

26. A method of operating an electromagnetic actuator, comprising:

providing first and second magnetic members and a first electromagnetic coil, the first magnetic member being moveable relative to the second magnetic member between first and second positions;

electromagnetically attracting the first magnetic member to the first position by electrical excitation of the first electromagnetic coil;

compressing a preloaded spring only as the first magnetic member moves from a position, spaced from the first and second positions, to the first position;

storing energy in the preloaded spring as the spool compresses the preloaded spring; and,

returning the energy stored in the preloaded spring to the first magnetic member as the first magnetic member moves from the first position towards the second position.

27. The method of claim 26, further comprising returning the first magnetic member to the second position by electrical excitation of a second electromagnetic coil.

28. The method of claim 26, further comprising returning the first magnetic member to the second position by a return spring.

29. The method of claim 28, further comprised of preloading the return spring

30. The method of claim 26, further comprised of maintaining the first magnetic member in the first position using a holding electrical current in the first electromagnetic coil.

31. The method of claim 26, wherein the position spaced from the first and second positions is closer to the first position than to the second position.

32. The method of claim 31, wherein the position spaced from the first and second positions is in the range of approximately one fifth to approximately one fourth of the way from the first position to the second position.

33. A method of operating a spool-type fluid control valve, comprising:

providing a magnetic spool, a magnetic spool valve housing and a first electromagnetic coil, the spool being moveable relative to the housing between first and second positions;

electromagnetically attracting the spool to the first position by electrical excitation of the first electromagnetic coil;

compressing a preloaded spring only as the spool moves from an intermediate position, spaced from the first and second positions, to the first position;

storing energy in the preloaded spring as the spool compresses the preloaded spring;

terminating electrical excitation of the first electromagnetic coil; and,

returning the energy stored in the preloaded spring to the spool as the spool moves from the first position towards the second position.

34. The method of claim 33, further comprising returning the spool to the second position by electrical excitation of a second electromagnetic coil.

35. The method of claim 33, further comprising returning the first magnetic member from the first position all the way to the second position by a return spring.

36. The method of claim 35, further comprised of preloading the return spring.

37. The method of claim 33, further comprised of maintaining the spool in the first position by continuously using a holding electrical current in the first electromagnetic coil.

38. The method of claim 33, wherein the intermediate position is closer to the first position than to the second position.

39. The method of claim 38, wherein the intermediate position is in the range of approximately one fifth to approximately one fourth of the way from the first position to the second position.

40. The method of claim 33, further comprising providing i) an instantaneous step increase in effective spring force, biasing the spool towards the second position, when the spool reaches the intermediate position from the second position and ii) an instantaneous step decrease in effective spring force, biasing the spool towards the second position, when the spool reaches the intermediate position from the first position.